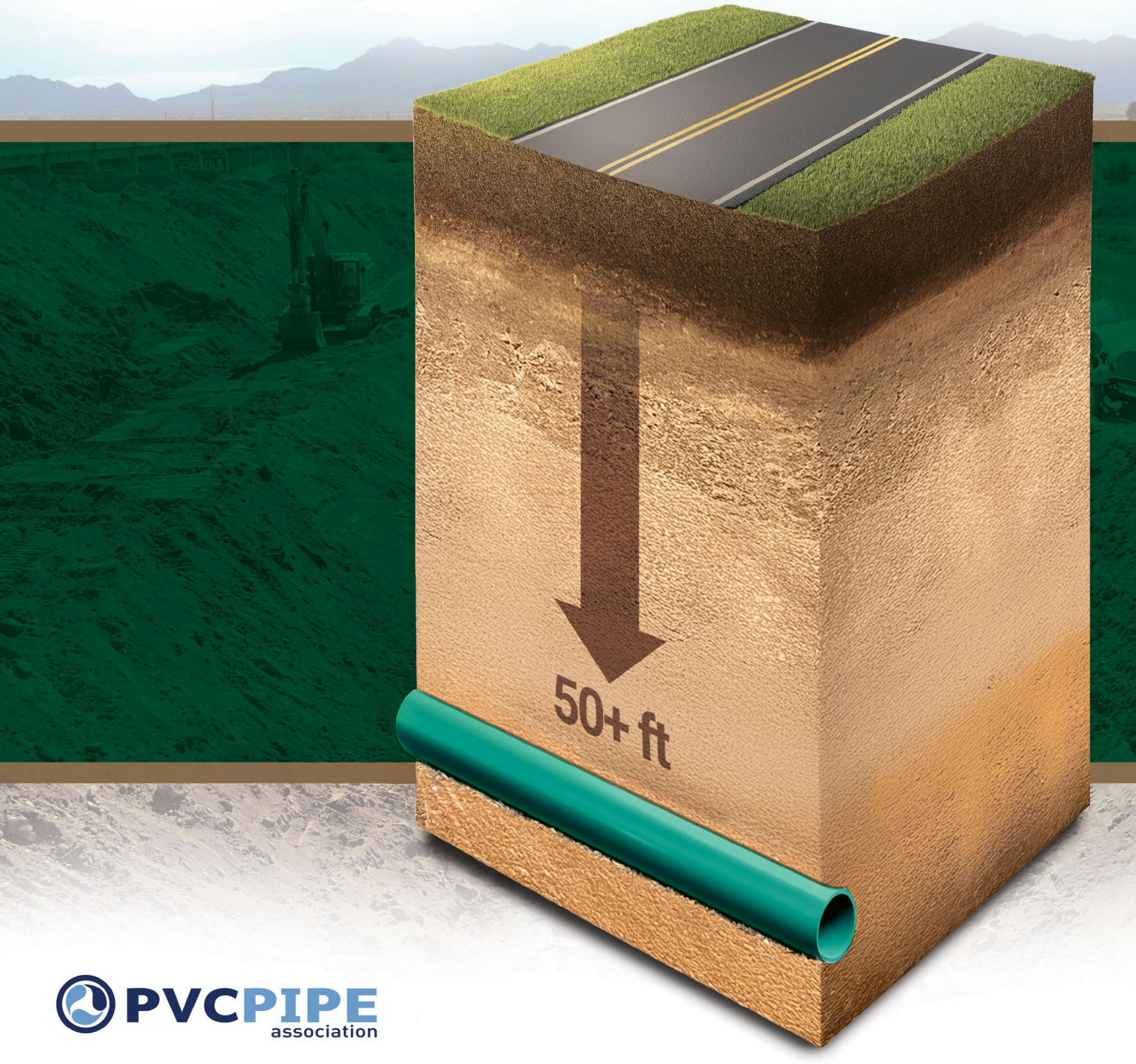
PVC Pipe in Deep-Bury Applications

FEA Modeling and Field Inspection of PVC Sewer Pipe



PVCPIPE association

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PVC Pipe: the Solution for Deep-Bury Applications

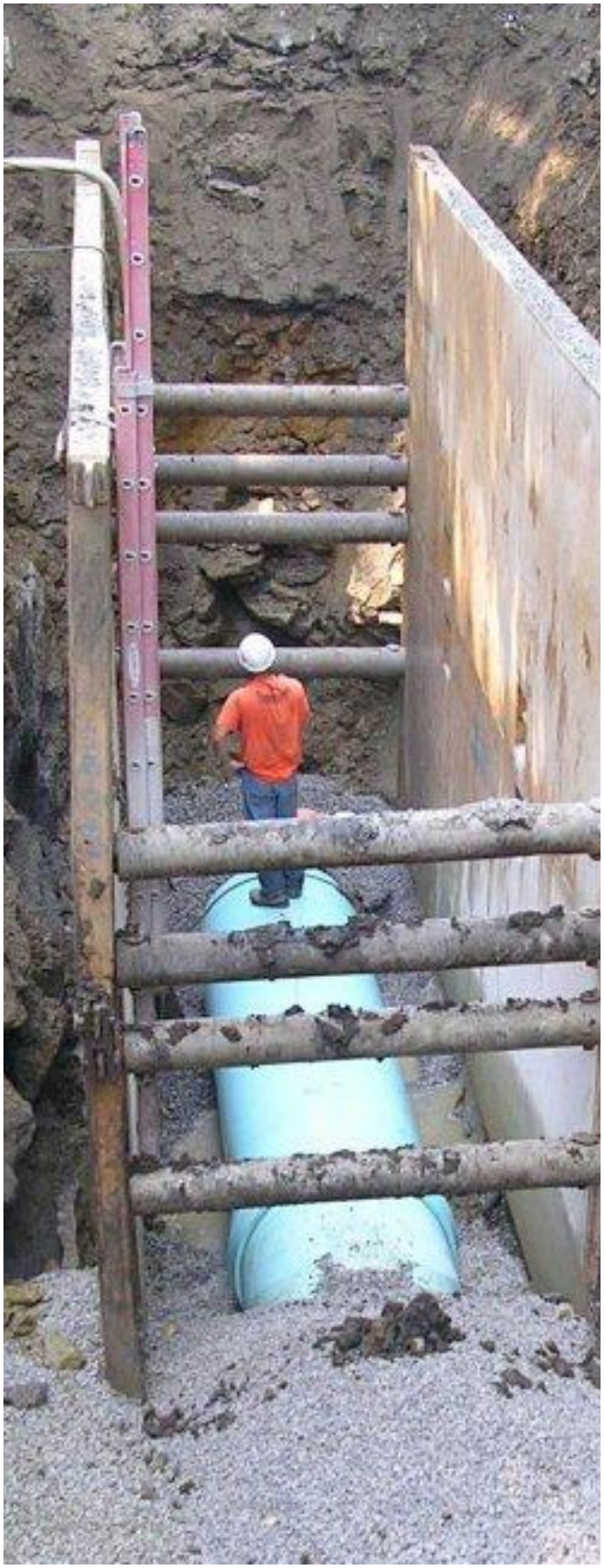
Over the last 60+ years, PVC pipe has been used extensively in North America for deep-bury sewer systems. Investigating the long-term structural performance of these pipes under external loads is critical to understanding their longevity and reliability.

In 2024, the PVC Pipe Association conducted comprehensive studies to confirm the performance of large-diameter PVC pipes in deep-bury applications through:

1. Finite element analysis (FEA) modeling of 36-inch PVC pipe at depths of cover from 20 to 50 feet
2. Laser profiling of a 21-inch PVC sewer interceptor in service for 45 years, installed at depths of up to 28 feet

FEA was used to simulate the structural behavior of PVC pipes under various loading conditions, while laser profiling provided detailed field data on deflections from an existing gravity sewer pipe interceptor. The primary objectives were to demonstrate the structural integrity of PVC pipe in deep-bury installations and validate the conservatism of current design practices.

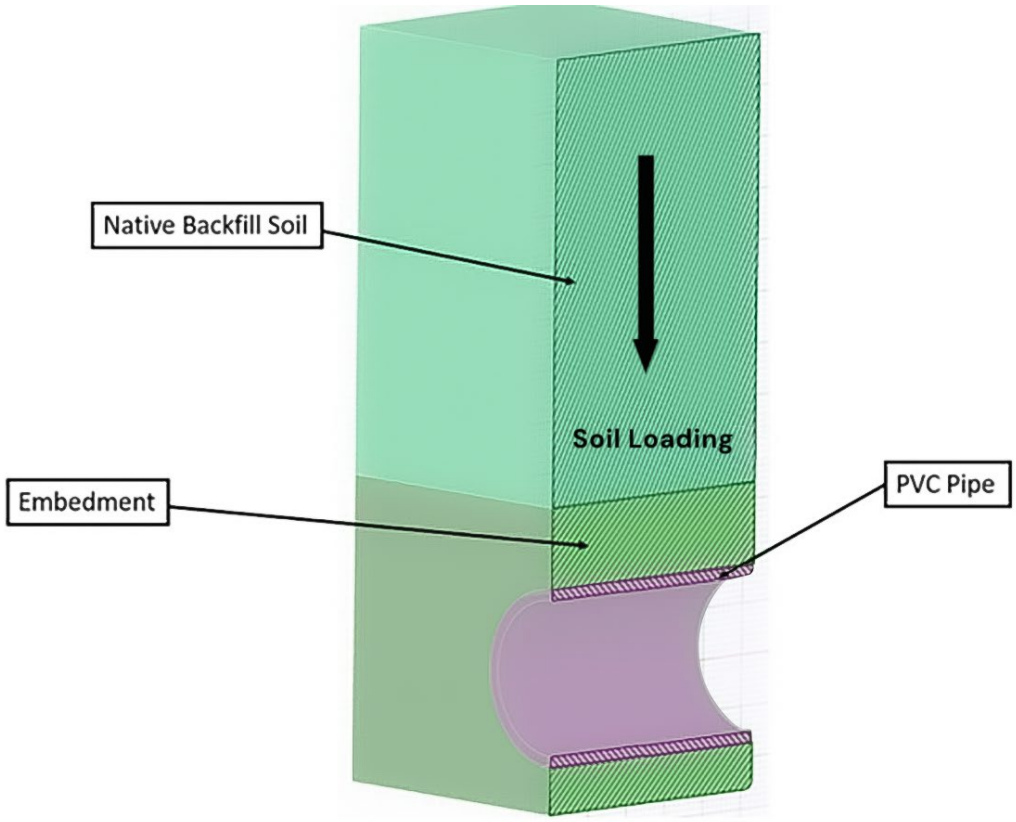
Design methods are not discussed in this document. For detailed information, see the *Handbook of PVC Pipe Design and Construction*.



FEA Modeling of PVC Pipe under External Loads

To simulate external loads that PVC pipes experience during service, FEA was performed at varying depths of cover to investigate their deflection characteristics and the soundness of current design practices.

The FEA model was based on a 36-inch diameter solid-wall PVC pipe (38.300-inch outside diameter) at depths of cover ranging from 20 to 50 feet. Two soil types were considered: imported (dumped crushed rock) and a common native material (moderately compacted lean clay). The modeling accounted for external load and pipe-soil interaction to replicate real-world loading conditions. To capture the high soil strains expected near the pipe, mesh refinement was applied at the pipe-soil interface.



Schematic of FEA Modeling of Soil Embedment Zone

Results of FEA Modeling

The modeling parameters and results are summarized in Table 1, showing deflections under different conditions. The table also includes calculated deflections using the Modified Iowa formula.

TABLE 1: RESULTS OF FINITE ELEMENT ANALYSIS

Iteration	Pipe Stiffness, psi	Pipe Wall Thickness, in.	Depth of Cover, ft	Embedment Type	FEA Pipe Vertical Deflection, in.	FEA Deflection, %	Calculated Deflection, %
1	46	1.094	20	Lean Clay Moderate Compaction	0.289	0.75%	2.46%
2	46	1.094	30	Lean Clay Moderate Compaction	0.442	1.15%	3.68%
3	46	1.094	40	Lean Clay Moderate Compaction	0.598	1.56%	4.91%
4	46	1.094	50	Lean Clay Moderate Compaction	0.756	1.97%	6.14%
5	46	1.094	20	Crushed Rock Dumped	0.062	0.16%	2.46%
6	46	1.094	30	Crushed Rock Dumped	0.108	0.28%	3.68%
7	46	1.094	40	Crushed Rock Dumped	0.130	0.34%	4.91%
8	46	1.094	50	Crushed Rock Dumped	0.231	0.60%	6.14%
9	115	1.473	20	Lean Clay Moderate Compaction	0.280	0.73%	2.13%
10	115	1.473	30	Lean Clay Moderate Compaction	0.429	1.12%	3.20%
11	115	1.473	40	Lean Clay Moderate Compaction	0.581	1.52%	4.27%
12	115	1.473	50	Lean Clay Moderate Compaction	0.735	1.92%	5.33%
13	115	1.473	20	Crushed Rock Dumped	0.050	0.13%	2.13%
14	115	1.473	30	Crushed Rock Dumped	0.078	0.20%	3.20%
15	115	1.473	40	Crushed Rock Dumped	0.106	0.28%	4.27%
16	115	1.473	50	Crushed Rock Dumped	0.135	0.35%	5.33%

Discussion of FEA Modeling Results

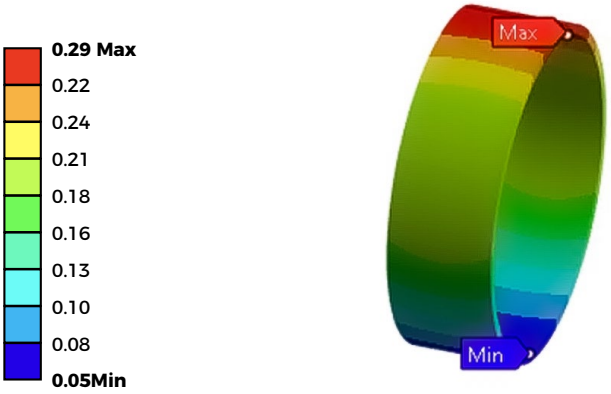
For the deep-bury conditions analyzed, deflections with crushed rock embedment were 0.60% or less while those with lean clay embedment were 2.0% or less. These are far below the 7.5% long-term limit for PVC pipe. Increases in wall thickness reduced deflection by a small degree which shows that PS 46 pipe is more than sufficient for most applications and depths of cover. This information confirms that PVC flexible pipe design is conservative since calculated deflections using the Modified Iowa formula were greater than shown by FEA modeling.

PVC Pipe Total Deformation with 20 ft Depth of Cover

1.094-inch Thick PVC Pipe with Lean Clay Moderate Compaction Embedment

Type: Total Deformation

Unit: in

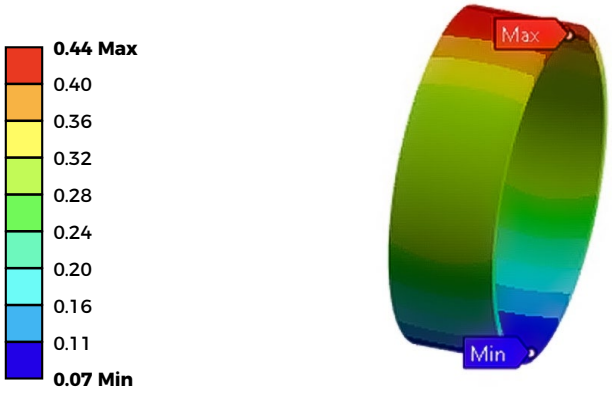


PVC Pipe Total Deformation with 30 ft Depth of Cover

1.094-inch Thick PVC Pipe with Lean Clay Moderate Compaction Embedment

Type: Total Deformation

Unit: in

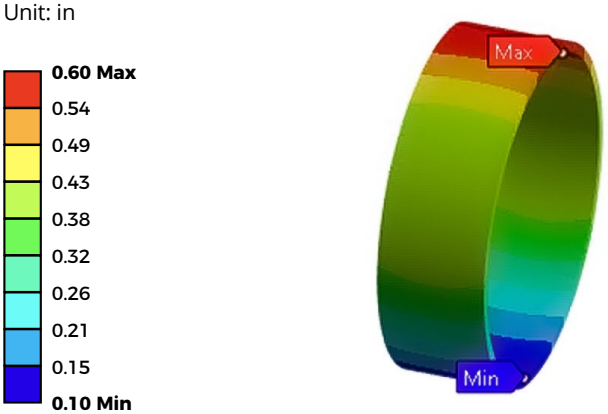


PVC Pipe Total Deformation with 40 ft Depth of Cover

1.094-inch Thick PVC Pipe with Lean Clay Moderate Compaction Embedment

Type: Total Deformation

Unit: in

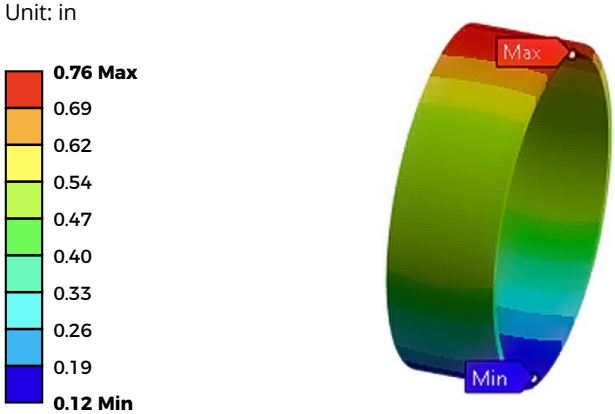


PVC Pipe Total Deformation with 50 ft Depth of Cover

1.094-inch Thick PVC Pipe with Lean Clay Moderate Compaction Embedment

Type: Total Deformation

Unit: in



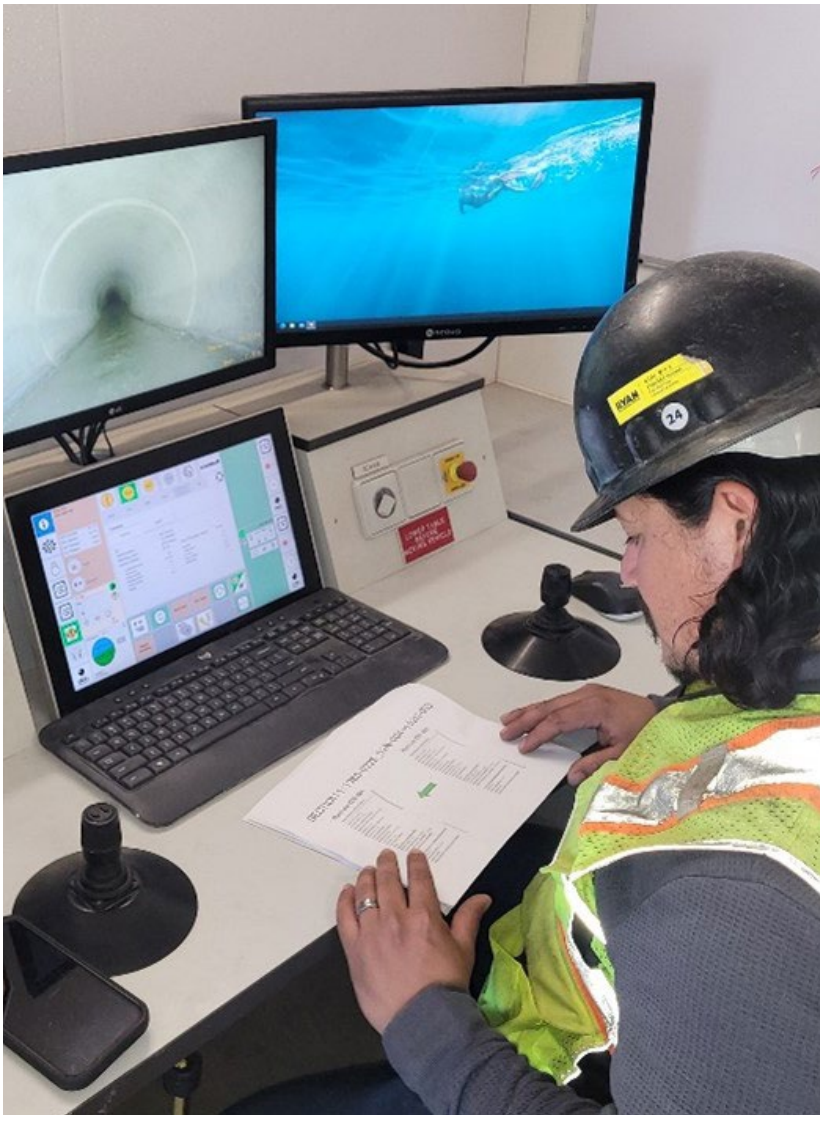
Design Iterations for Lean Clay with Moderate Compaction

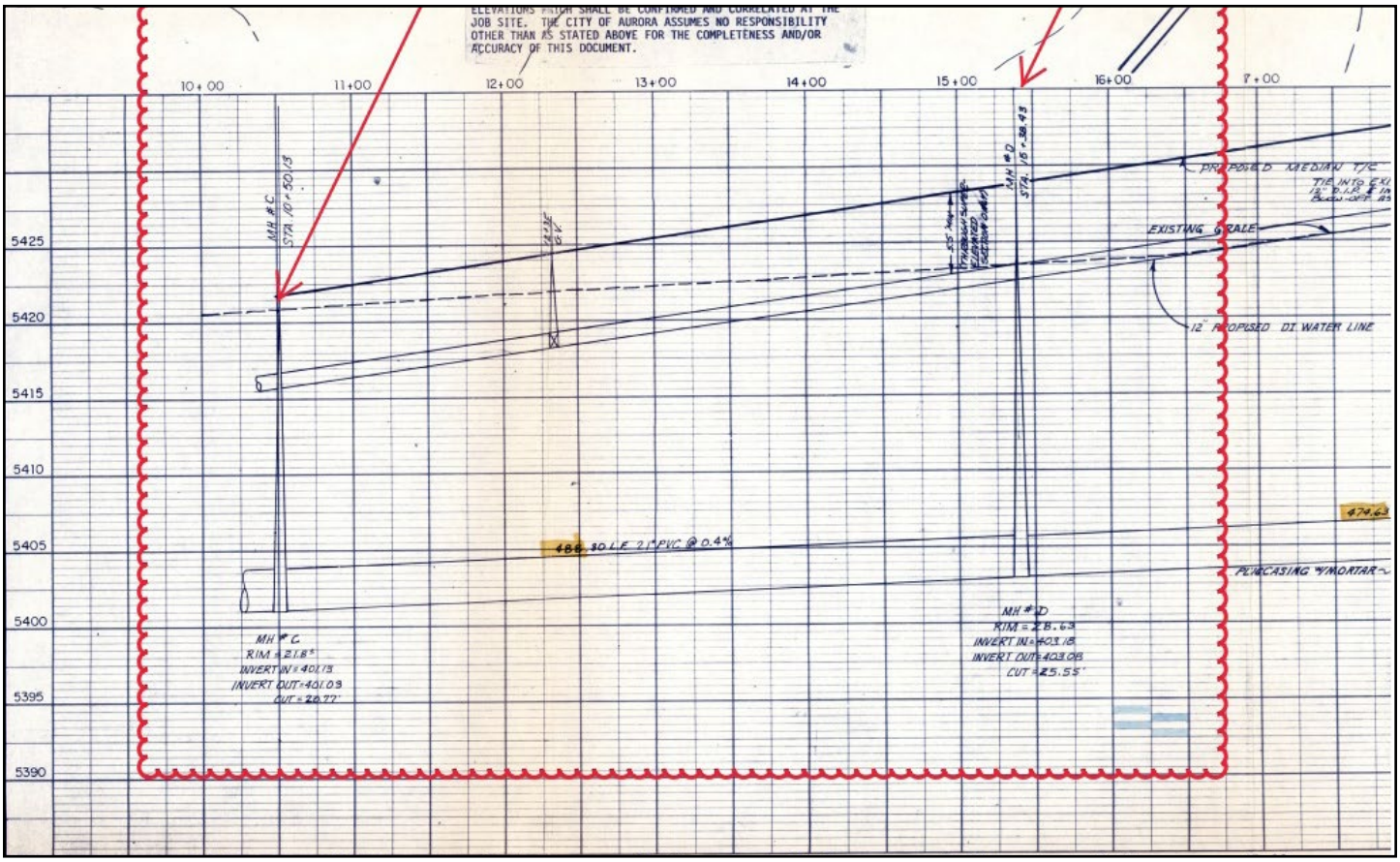
Laser Profiling of 45-Year-Old PVC Gravity Interceptor

The City of Aurora, CO, agreed to inspect a 21-inch PVC sewer pipeline in continuous service since 1980. The interceptor was located beneath a roadway and was installed at depths of cover up to 28 feet. As part of its routine maintenance program, the utility conducted a CCTV camera inspection of the pipeline in 2018. According to the City, the pipeline had performed according to specifications since it was installed:

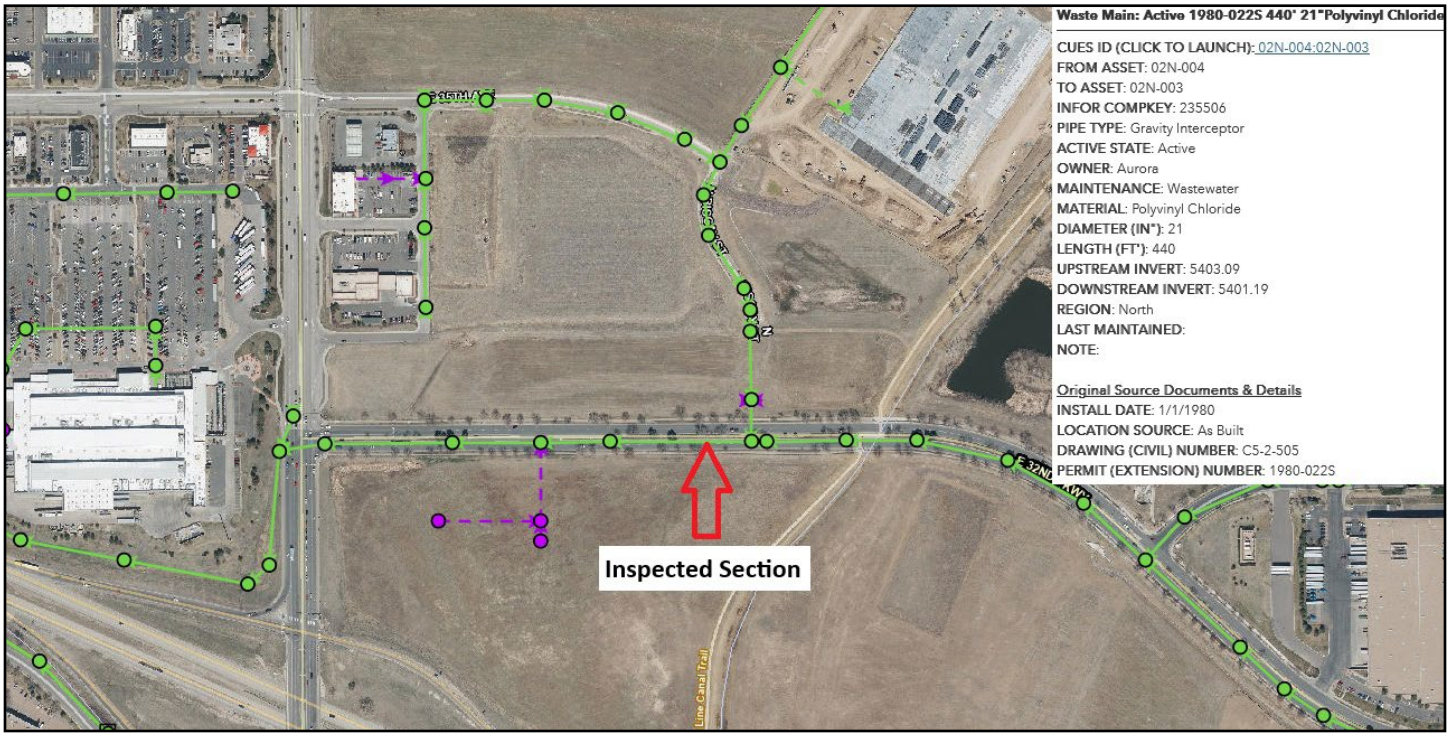
> *Operations and engineering are not aware of the pipe having any issues since its installation. The pipe has functioned as intended and conveys the sanitary flows as designed.*

Using a high-resolution HD Profiler system, a 427-foot segment of the pipeline was examined in May 2024. The laser profiler captured detailed data on the pipe's internal shape to determine if any deflection had been caused by external loads or settlements.





Installation Profile of Inspected Section



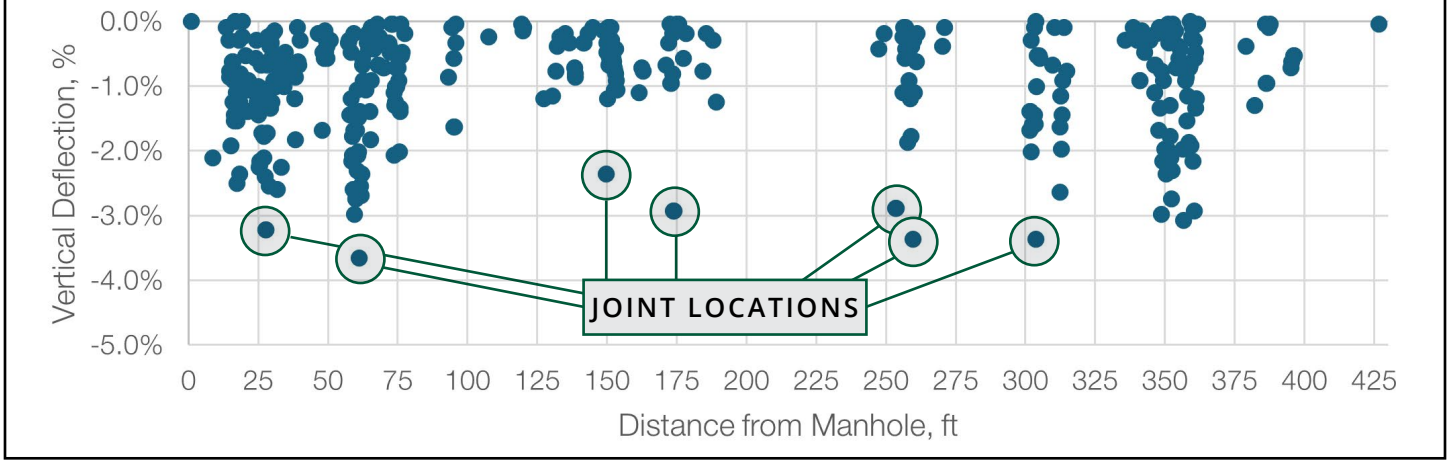
GIS Image Showing Location of Interceptor Inspection

Results of Laser Profiling

Figure 1 summarizes the results of the laser profiling and shows where along the length of the pipe the deflections were measured. Average deflection was determined to be 1.0%.

The pipe exhibited minor deflections that are well within acceptable limits for PVC pipes in service. At joint locations, where measurement discontinuities are to be expected, a few readings were at or above 3.0%. Downward spikes at the joints do not reflect a true deflection due to soil load. Thus, the actual average pipe deflection is smaller than what was measured. These results show the PVC interceptor has performed well throughout its 45 years of service and can be expected to meet or exceed the 100+ year service life.

FIGURE 1: VERTICAL DEFLECTION OF PVC GRAVITY SEWER PIPE



Inside the Deep-Bury Interceptor in Aurora, CO

Key Report Findings

FEA modeling and laser profiling of PVC gravity sewer pipe confirm the following:

- **Even under Extreme Loading Conditions, Deflections Observed for PVC Pipe Are Lower than Expected**
  FEA modeling shows that minimal deflections occur in deep-bury environments (20 to 50 feet) with PVC pipe in various soil embedments. This demonstrates that recommended design practices are based on conservative assumptions – providing an adequate safety factor for reliable long-term service.

- **Field Testing of 45-Year-Old Pipe Shows Inconsequential Deflections**
  Only minor deflections (1.0 % or less) were observed on a 45-year-old PVC gravity sewer pipe after conducting laser profiling. All measurements were well below acceptable limits, demonstrating PVC pipe's suitability to withstand long-term external loads in deep-bury applications.

Comparing FEA modeling and laser profiling data provides an interesting insight. FEA shows that with depths of bury from 20 to 30 feet of cover, deflections are roughly 1% or less. Laser profiling of 45-year-old PVC pipe indicates that the deflections are mostly under one percent in the same depth of cover range. Together, these results confirm that PVC pipes perform as designed and are not subject to increases in deflection over time. The studies serve to reassure utilities that PVC pipe is an excellent choice for deep-bury applications.

Previous Research Validates Suitability of PVC Sewer Pipe in Deep-Bury Applications

PVC pipes have been subject to extensive evaluation over the years which support the findings of this report:

- In 1981, Moser and Shupe established that PVC pipes do not fail catastrophically. PVC pipe does not lose ovality until nearly 30% deflection – reaching this level of deflection with DR 35 pipe in silty sand with 80% standard Proctor density compaction would require burial depths between 60 and 100 feet.

- In 1999, Moser and Bishop documented that after 22 years under constant deflection (i.e., constant strain), PVC pipe does not experience a reduction in modulus of elasticity or pipe stiffness.

PVC Pipe Proven Ideal for Deep-Bury Installations

Both FEA modeling and laser profiling of in-service pipe provide conclusive evidence that PVC is well suited for deep-bury applications. Conservative design methodology ensures that even under challenging loading conditions, PVC pipes maintain structural integrity and can be expected to remain in service for more than 100 years.

Evidence of PVC pipe's long-term reliability is also supported by the fact that there are 1.4 million miles of solid-wall PVC sewer pipe installed in North America, confirming it is the best material for both large- and small-diameter gravity sewer systems.

Acknowledgements

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